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ELECTRIC TESTING
OF
TELEGRAPH CABLES

CAP^{N}. V. HOSKIÆR

ELECTRIC TESTING

OF

TELEGRAPH CABLES.

A GUIDE

FOR THE

ELECTRIC TESTING

OF

TELEGRAPH CABLES.

BY

CAPTAIN V. HOSKIÆR,

ROYAL DANISH ENGINEERS.

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PREFACE.

HAVING had the control of the manufacture of about 3500 nautical miles of Telegraph Cables, made mostly with Hooper's Core, but also with Core of ordinary Gutta-percha and of Willoughby Smith's Gutta-percha, I have had frequent opportunities of ascertaining the correctness of the data named in this book.

I do not expect an Electrician will discover anything new in these pages, but if he should find this Guide a useful one to put in the hands of young men, who have to learn practical testing, I shall feel satisfied in having published it.

V. H.

LONDON, *August*, 1873.

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ELECTRIC TESTING OF TELEGRAPH CABLES.

1. ELECTRIC TESTS.

THE electric Testing employed during the fabrication of Cables (or Cores) ascertains the following points:

A. The Conductivity of the Copper.
B. The Charge of the Cable.
C. The Insulation of the Cable.
D. The Insulation of a Joint.
E. The Situation and Greatness of a Fault.

2. COMMON DEGREE OF HEAT.

As the heat has an essential influence on the electric condition of a Cable by diminishing the conductivity of the Copper and the insulation of the Cable, all the results obtained by the tests ought to be transferred by calculation to the same degree of heat. For this purpose a common degree of 75° Fahrenheit (c. 24° Celsius) has been chosen.

3. IMMERSING UNDER WATER.

As the air is a less good electric conductor than water, and as the greatness of the charge depends on how the electricity in the Copper influences the water outside the insulation, the Cable has during the determination of its charge and its insulation always to remain immersed *under* *water*, which water must be in electric connection to Earth, for instance, through an iron tank.

4. DISCHARGING BEFORE TESTING.

When a Cable has to be tested, it ought to be discharged, by connecting it to earth during some hours before the test.

5. APPARATUSES.

For electric tests the following Apparatuses are principally used:

Batteries (B) up to 500 elements.
Thomson's Reflecting Galvanometer (G) with Shunt (Sh).
Condenser (Cd).
Reversing Battery-keys (B.K).
Short-circuit Keys (S.K).
Charge and Discharge Keys (D.K).
Commutators (Cm).
Wheatstone's Bridge (W.B.) with Shunt (Sh).
Resistance-coil (R).

6. THE USE OF A SHUNT.

A Shunt is generally used together with a Galvanometer, and connected to it in such a way that only a part of the electric current passes through the Galvanometer, while the rest passes through the Shunt. An appropriate Shunt must be used in order that the deflection of the Galvanometer may not be too large. The resistance of the Shunt diminishes as the length of the Cable or the sensibility of the Galvanometer increases.

The *multiplying power* v of the Shunt is $= \frac{s+g}{s}$, where s is the resistance of the Shunt, and g the resistance of the

Galvanometer. Should, for instance, s be $= 1$, and $g = 99$, v will be $= \frac{1+99}{1} = 100$; then only $\frac{1}{100}$ part of the whole current will pass through the Galvanometer, and the current will therefore be 100 times greater than is indicated by the deflection of the Galvanometer.

Should it be desired to give the Shunt a certain power, its *resistance* s can be found from the previous equation, as s is $= \frac{g}{v-1}$.

When a current passes a Galvanometer with the resistance g, and a Shunt with the resistance s, the *total resistance* of Galvanometer and Shunt is $= \frac{g \times s}{g+s}$. In the calculation of the insulation it is not thought necessary to take notice of these two resistances.

7. ELECTRIC UNITS.

The *Unit of Resistance* is:

1 Ohm = 1 British Association Unit = 1 B.A.U. = 10 Million Units of resistance, or:

1 Siemens' Unit = 1 S.E., the resistance of a prism of mercury, 1 meter long, and 1 □ millimeter in section at 0°C.

1 Ohm = 1·070 S.E.

1 S.E. = ·935 Ohm.

1 Megohm = 1 Million Ohms.

The *Unit of Tension* is = 1 Volt = 100000 Units of Tension.

The *Unit of Quantity* = 1 Weber.

The *Unit of Charge* is = 1 Microfarad = 1 Millionth part of a Farad.

8. THE ORDER OF THE TESTS.

The Tests are best taken in the following order:

Resistance of the Galvanometer.
Conductivity of the Copper.
Charge of the Leading wires.
" of the Cable after 1 minute's Insulation.
" " by instantaneous Discharge.
Constant *c* of the Condenser.
Constant *n* of the Battery.
Constant ϕ of the Galvanometer.
Insulation of the Leading wires.
Insulation of the Cable.

A.—THE CONDUCTIVITY OF THE COPPER.

9. EXPLANATION OF THE METHOD.

In the electric test with the Cable, the positive current from the Copper (C, Fig. 1) in the Battery (B) is generally led to Earth (E). The negative current from the Zinc (Z) is led through a wire (W) to Wheatstone's Bridge (W.B.), and divides itself at *a* into two parts, whereof the one goes through *a b*, *b c*, and the Cable (Ca) to Earth, whilst the other goes through *a c*, *c b*, and the Resistance-coil (R) to Earth. It is clear that the connection to Earth can be omitted, and C directly connected with *d*.

By removing the plug *e*, the two opposite currents from *b* to *c* and from *c* to *b* pass through the Galvanometer (G) with Shunt (Sh). There will be no deflection on the Galvanometer, if the currents have the same strength, which they have, if

$$\text{the resistance in } a\,b : \text{the resistance in } a\,c = \text{the resistance in R} : \text{the resistance in Ca},$$

thus when

$$\frac{ab}{ac} = \frac{\mathrm{R}}{\mathrm{Ca}}, \text{ or when } \mathrm{Ca} = \frac{ac}{ab}\mathrm{R} = \mathrm{R}'.$$

By $a\,c = a\,b$, Ca is $=$ R; but the proportion between the resistance $a\,c$ and $a\,b$ can be varied from $\frac{1000}{10}$ to $\frac{10}{1000}$, and this proportion is named *Ratio of balance.*

The Resistance R is now to be varied until the beam of light from the Galvanometer covers the zero on the scale; it will perhaps be found that the beam of light moves to the left in diminishing R, that is by inserting a plug into the Resistance-coil. It must be carefully attended to, that the plugs in the Resistance-coil are clean.

When a paid out Cable is affected by earth-currents, it is necessary to test alternately with the Zinc-pole and the Copper-pole, and take the mean of the tests.

10. PRACTICAL EXECUTION OF THE TEST.

For the test are used the apparatuses indicated in Fig. 2.

The Copper-pole (C) of the *Battery* (B) is, by lifting *g*, connected, through *i* and *l* in the Key B.K, to the screw *m* in the Resistance-coil (R); the Zinc-pole (Z) is connected, by depressing *f*, through *h* and *k* in the Key B.K, to the screw *z* in Wheatstone's Bridge. The Battery has from 4 to 10 elements.

The two ends *n* and *o* of the *balance* are directly connected with the bridge *d e* of the Galvanometer. *Ratio of balance* is generally at the testing of the Core and of the Leading wires $= \frac{1000}{10}$, of the Cable $= \frac{1000}{100}$, and of the Galvanometer $= \frac{1000}{1000}$.

The one end of the *Cable* is connected to *m*, the other to *n*.

When *f* is depressed the current goes through the Cable and the Resistance R, which is varied until there is no deflection on the Galvanometer.

The resistance in the Cable is now calculated by aid of the numbers for the ratio of balance and for the indicated Resistance (R).

The resistance in the *Leading wires* is found in the same way as the resistance in the Cable, by removing the Cable, and only fixing the Leading wires between *m* and *n*.

11. CALCULATION OF THE CONDUCTIVITY.

Should the real resistance of the Cable and Leading wires be = R′, and the real resistance of the Leading wires = L, the Resistance R_2 of the Cable only will be $= R' - L$.

An *Ohm* is used as the unit of resistance. Should, therefore, the Resistance R_2 have been determined in Siemens' Units, it will, when expressed in Ohms, be: $R_2 \times \cdot 935$.

Should the length of the Cable be $= l$ knots (nautical miles), the resistance per knot will be:

$$\frac{R_2 \times \cdot 935}{l}.$$

As the resistance of the copper increases ·21 per cent., or ·0021 for every degree Fahrenheit the temperature rises, if the test is made at a temperature t, the resistance at 75° F. will be:

$$\frac{R_2\,(1 + \cdot 0021\,(75^\circ - t)\,)\cdot 935}{l}.$$

Should the Resistance R_2 have been found at 85°, the resistance at 75° will be: $R_2 (1 - \cdot 021) = \cdot 979\ R_2$ (see Table I.).

As a wire of pure copper with the length of 1 knot and the weight of 1 lb. has at 75° F. a resistance of 1192·33 Ohms, a wire with the weight of P lbs. per knot will have a resistance of $\frac{1192 \cdot 33}{P}$ Ohms. The Core of the China-Japan Cable, with a weight of 300 lbs. copper per knot, would therefore have a resistance $= \frac{1192 \cdot 33}{300} = 3 \cdot 9744$ Ohms, if it were of pure copper.

The conductivity of the copper conductor of this Cable, expressed in a percentage of the conductivity of pure copper, or the *specific conductivity* of the conductor, is therefore:

$$x = \frac{3 \cdot 9744 \times 100 \times l}{R_2 (1 + \cdot 0021 (75\text{-}t)) \cdot 935}.$$

Generally several Cables are tested at the same time, and the calculation is then facilitated by the use of *logarithms*, which are best taken in the following order:

$$\log. x = - \log. R_2 - \log. \cdot 935 - \log. (1 + \cdot 0021 (75\text{-}t)) + \log. l + \log. 3 \cdot 9744 + \log. 100.$$

12. THE RESISTANCE OF THE GALVANOMETER.

The resistance of the Galvanometer, used at the testing of the charge and the insulation of the Cable, has to be found in the same way as the resistance of the Cable, by placing the Galvanometer instead of the Cable between *m* and *n* (Fig. 2); the ratio of balance used is $= \frac{1000}{1000}$.

If only *one* Galvanometer can be had for the testing, its resistance can be found as follows:—The resistance of the Galvanometer at a certain degree F. being always exactly given by the manufacturer of the Galvanometer, its resistance at the existent temperature, read on a thermometer, fixed on the Galvanometer, is calculated by the resistance in its copper wires which increases ·0021 for every degree F. the temperature rises. A Table for the resistances between 40° and 75° F. ought to be calculated for each Galvanometer, and its correctness ascertained by comparing these resistances with those obtained in the ordinary way by using a second Galvanometer.

If the resistance of the Galvanometer at 60° F. is 10600 Ohms, its resistance at 65° F. will be:

$$10600\,(1 + {\cdot}0021 \times 5) = 10711 \text{ Ohms.}$$

13. THE RESISTANCE OF THE BATTERY.

To find the Resistance of a Battery connect its Copper-pole C (Fig. 2) to Earth, and its Zinc-pole with the button *e* of the Galvanometer. Connect the two buttons, *e* and *d*, of the Galvanometer by a copper wire of small resistance, and put *d* to Earth. By depressing *f* the current passes through the shunted Galvanometer to Earth, and a certain deflection u is found on the scale. Then is put between the Zinc-pole and the Galvanometer a Resistance R so great, that the deflection is only $= \frac{u}{2}$, and R is = the resistance of the battery.

With a Daniell's battery of 140 Cells and a Galvanometer with a resistance of 10700 Ohms a copper wire with a resistance of ·2 Ohm was used and a deflection of 120° was found. By placing into the current a resistance of 3500 Ohms, there was found a deflection of 60°, and the resistance of the battery was then 3500 Ohms, or 25 Ohms per Cell.

14. THE RESISTANCE OF THE EARTH.

To find the resistance of the Earth one Cell is connected by its Copper-pole to Earth, and by its Zinc-pole through a great resistance and the Galvanometer to Earth; a certain deflection is then found on the Galvanometer scale. The two wires, one from the Copper-pole and the other from the Galvanometer, are then connected together, instead of being both led to Earth, and the deflection has to be the same as before, if the Earth-plates are in good order. Should this last-read deflection be greater than the first one, the Earth is faulty; and as this often arises from the Earth being dry, this fault may often be prevented only by keeping the Earth drenched.

15. EXAMPLES.

Example 1.

Length of the Core .. .. = 5 knots.
Temperature .. .. = 70° F.
Number of elements in the Battery .. = 4.
Ratio of balance .. .. = $\frac{1000}{10}$.

The following columns are daily to be filled up in a *journal* with ciphers, which in columns No. 1 and 2 are given, in

Nos. 3, 4 and 9 are read on the Resistance-box, and in Nos. 5 to 8 are to be calculated.

Length of Core in knots.	Temperature.	Indicated Resistance of Leading Wires.	Indicated Resistance of Core and Leading Wires.	Real Resistance of Core.	Resistance at 75° F.	Resistance per knot at 75° F.	Specific Conductivity.	Resistance of Galvanometer.
1	2	3	4	5	6	7	8	9
5·000	70°	130	2244	21·14	21·36	4·272	93·03	5850

The *real resistance* of the Core is: the resistance of the Core and Leading wires, minus the resistance of the Leading wires, divided by ratio of balance, or:

$$\frac{2244 - 130}{\frac{1000}{10}} = 21 \cdot 14 \text{ Ohms.}$$

As the test has been taken at a *temperature* of 70° F. the resistance of 75° F. will be:

$$21 \cdot 14\,(1 + \cdot 0021 \times 5) = 21 \cdot 36 \text{ Ohms.}$$

As the *length* of the Core is 5 knots, the resistance per knot at 75° is:

$$\frac{21 \cdot 36}{5} = 4 \cdot 272 \text{ Ohms.}$$

As the resistance of pure Copper with a weight of 300 lbs. per knot is only 3·9744, the *specific conductivity* of the Copper conductor will be:

$$\frac{3 \cdot 9744 \times 100}{4 \cdot 272} = 93 \cdot 03.$$

The conductivity is calculated by the use of *logarithms* as follows:

$$\log. x = -\log. 21\cdot14 - \log. 1\cdot0105 + \log. 5 + \log. 3\cdot9744 + \log. 100,$$

$$\begin{array}{lrl}
\text{or } \log. 21\cdot14 & = 1\cdot3251050 & \\
\log.\ 1\cdot0105 & = 0\cdot0045363 & \\
 & \overline{} & 1\cdot3296413 \\
\log.\ 5 & = 0\cdot6989700 & \\
\log.\ 3\cdot9744 & = 0\cdot5992716 & \\
\log.\ 100 & = 2\cdot0000000 & \\
 & \overline{} & 3\cdot2982416 \\
 & & \overline{} \\
 & \log. x & = 1\cdot9686003 \\
 & x & = 93\cdot03
\end{array}$$

EXAMPLE 2.

Length of the Cable .. .. = 100 knots.
Temperature .. .. = 70° F.
Number of elements .. .. .. = 5.
Ratio of balance .. .. .. = $\frac{1000}{100}$.

The following results will be found:

Length of Cable in knots.	Temperature.	Indicated Resistance of Leading Wires.	Indicated Resistance of Cable and Leading Wires.	Real Resistance of Cable.	Resistance at 75° F.	Resistance per knot at 75° F.	Specific Conductivity.	Resistance of Galvanometer.
1	2	3	4	5	6	7	8	9
100	70°	31·3	4260·3	422·9	427·3	4·273	93·00	5955

B.—THE CHARGE OF THE CABLE.

16. PRACTICAL EXECUTION OF THE TEST.

The arrangements of the apparatus are indicated in Fig. 3.

The Copper-pole C of the Battery B is connected through the Key B.K to Earth, and the Zinc-pole Z is connected through the Key B.K to the screw *s* of the Discharge-key D.K.

The screw *s* of the Charge or Discharge-key D.K being connected to the Zinc-pole, the screw *t* is connected through the Galvanometer with Shunt to Earth, and the screw *u* is connected through the plug *p* of the Commutator Cm with one end of the Cable.

The other end of the *Cable* is well isolated.

The end screws *m* and *n* of the *Shunt* Sh are connected to the screws *e* and *d* in the bridge of the Galvanometer. When a Battery has 10 elements, a Shunt has been used at the Cable, which Shunt varied from 200 to 10, as the length of the Cable increased from 10 to 200, the Shunt multiplied by the length or the Charge of the Cable always giving the same number. A Shunt of 2000 has been used at a Condenser, which had a charge of ·50 Microfarad; the Shunt of 2000 multiplied by the Charge ·50 is here = 1000.

When the Cable has been charged for one minute by depressing the button *q* of the Discharge-key, *q* is released and *r* depressed, and the Cable will be discharged through the Galvanometer with Shunt to Earth.

300° to the right of zero may be taken as the starting point, so as to be able to have as great a deflection on the scale of the Galvanometer as possible, and the deflections are then read to the left.

17. CONSTANT *c* OF THE CONDENSER.

At the determination of the charge a Condenser is used, the full charge of which has a certain given size; in the Core factory the charge of the Condenser was ·319 Microfarad, in the Cable factory it was ·50 Microfarad.

When the *charge of the Condenser* is to be measured, the Condenser, instead of the Cable, is brought into the current (Fig. 3) by removing the plug *p* to *p′*. The one end of the Condenser is joined through the plug *p′* in the Commutator Cm, and through *u* and *s* in the Discharge-key to the Zinc-pole; its other end to Earth. The Condenser is charged in 1 minute by depressing *q*; it is thereon discharged instantaneously through the Galvanometer with Shunt, by releasing *q* and depressing *r*. In the reading on the scale of the Galvanometer of the deflection U_3, which generally is put = Constant *c*, a Shunt must be used of such a size, that the deflection from the Condenser will be found on about the same point of the scale as the deflection from the Cable.

18. CALCULATION OF THE CHARGE.

The *Cable* (including the Leading wires) is *charged* in 1 minute, then *isolated* in 1 minute, by releasing *q*; the Cable is then discharged by depressing *r*; the charge passes through the Galvanometer to Earth, and on the scale of the Galvanometer a deflection U will be obtained.

The Cable is then charged in 1 minute and *instantly discharged*, whereby a deflection U′ is obtained.

The percentage of *loss of charge* in the Cable in 1 minute is then:

$$\frac{U' - U}{U'} \times 100.$$

The *Leading wire*, when charged in 1 minute and then discharged instantly, gives a deflection $= u$, and the charge after 1 minute of the Cable alone is then expressed by:

$$U' - u = U_2.$$

The *Condenser*, when charged in 1 minute and instantly discharged, gives a deflection U_3, which is generally named *Constant c.*

At Cables of short lengths, as at Leading wires and at Condenser, it may be sufficient to charge for 15 seconds instead of 1 minute.

If the Condenser has an inductive capacity C, then the *specific inductive capacity x* of the Cable is expressed by:

$$\frac{\text{Deflection } U_3}{\text{Ind. Cap. } C} = \frac{\text{Deflection } U_2}{\text{Ind. Cap. } x}, \text{ or:}$$

$$x = \frac{U_2 \times C}{U_3} = \frac{U_2 \times C}{c}.$$

When a *Shunt* has been used at the Cable with a resistance s, and thus has a multiplying power $v = \frac{s + g}{s}$, where g is the resistance of the Galvanometer, and when a Shunt has been used at the Condenser with a resistance s', and thus has a multiplying power $v' = \frac{s' + g}{s'}$, the deflection c has to be multiplied with v' and divided by v, and thus will be found:

$$\frac{U_2 \times C}{c \times \frac{v'}{v}} = \frac{U_2 \times v \times C}{c \times v'}.$$

As the inductive capacity of a Cable is directly proportionate to its length, the ***inductive capacity per knot***, when the Cable has a length l, will be:

$$x = \frac{U_2 \times v \times C}{c \times v' \times l}.$$

Should *logarithms* be used, the formula will be:

$$\log. x = \log. C + \log. v + \log. U_2 - \log. c - \log. v' - \log. l.$$

19. EXAMPLES.

EXAMPLE 1.

Length of Core = 5 knots.
Number of elements = 20.
Inductive capacity of the Condenser = ·319 Microfarad.
Shunt of the Core = 100 Ohms.
Shunt of the Condenser = 500·Ohms.
Resistance of the Galvanometer = 5850 Ohms.
Deflection by discharge of the Leading wires = 2.

The following columns are daily to be filled up in a *journal*:

Shunt at the Core.	Deflection after 1^m Charge and 1^m Insulation.	Deflection after 1^m Charge.	Percentage of Loss of Charge.	Shunt at the Condenser.	Deflection from Condenser = c.	Total Charge.	Charge per Knot.
1	2	3	4	5	6	7	8
100	652°	662°	1·51	500	450°	2·199	·4398

The deflections 2, 3, and 6 are read to the left side of the scale with 300° to the right of zero as starting point. The deflections noted under 2 and 3 are the deflections from which, when read, are subtracted the deflection from the Leading wires.

The percentage of *loss of charge* is:

$$\frac{662 - 652}{662} \times 100 = 1{\cdot}51.$$

As the Shunt of the Core has a multiplying power $v = \frac{100+5850}{100} = 59{\cdot}50$, and the Shunt of the Condenser a multiplying power $v' = \frac{500+5850}{500} = 12{\cdot}70$, the reduced deflection of the Condenser is $= 450 \times \frac{12{\cdot}70}{59{\cdot}50} = 96{\cdot}05$.

The whole charge of the Core is found by

$$\frac{{\cdot}319}{96{\cdot}05} = \frac{x}{662}$$

$$x = \frac{{\cdot}319 \times 662}{96{\cdot}05} = 2{\cdot}199.$$

The *charge per knot* of the core is:

$$\frac{2{\cdot}199}{5} = {\cdot}4398.$$

When *logarithms* are used there will be found:

log. x = log. ·319 + log. 59·50 + log. 662 − log. 450 − log. 12·70 − log. 5.

log. ·319 = 0·5037907 − 1
log. 59·50 = 1·7745170
log. 662 = 2·8208580
4·0991657
log. 450 = 2·6532125
log. 12·70 = 1·1038037
3·7570162

log. 2·199 = 0·3421495
log. 5 = 0·6989700

log. x = 0·6431795 − 1
x = 0·4398

EXAMPLE 2.

Length of Cable .. .. = 100 Knots.
Number of Elements .. = 10.
Charge of the Condenser. = ·50 Microfarad.
Shunt of the Cable.. .. = 20 Ohms.
Shunt of the Condenser.. = 2000 Ohms.
Resistance of Galvanometer = 5955 Ohms.
Deflection from the Leading wires = *o*.

Shunt at the Cable.	Deflection after 1^m Charge and 1^m Insulation.	Deflection after 1 Charge.	Percentage of Loss of Charge.	Shunt at the Condenser.	Deflection from Condenser.	Total Charge.	Charge per Knot.
1	2	3	4	5	6	7	8
20	482°	489°	1·50	2000	418°	44·0	0·4400

C.—THE INSULATION OF THE CABLE.

20. PRACTICAL EXECUTION OF THE TEST.

The arrangement of the apparatuses is indicated in Fig. 4.

The Copper-pole of the *Battery* is connected to Earth, and the Zinc-pole to the screw *b* of the Short-circuit Key S. K; the one end of the Cable is connected to the screw *c* of the Key S. K, whilst its other end is well isolated.

When *f* is depressed, the current from Z passes through the Short-circuit Key from *b* through *c* into the Cable, the other end of which is isolated, so that the current is obliged to pass through the insulation to Earth. In order that the strong current may not too violently affect the Galvanometer, the button *a* is not depressed, and the Galvanometer thereby put into the current, until ½ minute after the current is closed. When *a* is depressed, the current on arriving at *b* and *e*, on its way into the Cable, will divide into two parts, of which the one passes through the Shunt Sh, the other through the Galvanometer G, the deflection of which will give a measure of the strength of the current. The resistance which the current meets in the Dielectric so far surpasses all the other resistances in the line, that it is not necessary to take notice of the latter. It is therefore supposed that the deflection is in inverse proportion to the resistance of the Dielectric alone.

If the insulation of a Core is very small, say under 1,000,000 Ohms, it can be found in the same way as the copper-resistance (Fig. 2), the Core being connected to the screw *n* of the Resistance-box, and having the other isolated, and not as at the test of copper-resistance connected to the screw m. The numbers for the ratio of balance multiplied with the Resistance R give the insulation of the Cable.

21. OHM'S LAW.

According to Ohm's Law:

$$\text{the strength of the current is} = \frac{\text{The Electromotive force E}}{\text{Resistance } x}.$$

As the strength of the current is here measured by the deflection U of the Galvanometer, it will be found that

$$U = \frac{E}{x}, \text{ or:}$$

$$\text{the resistance } x \text{ of the Insulation} = \frac{E}{U}.$$

As the greatness of E and U varies daily, E depending not only on the number, but on the strength of the elements, and U on the sensibility of the Galvanometer, these two factors must daily be measured by reference to some unit.

22. CONSTANT n OF THE BATTERY.

The electromotive force of the Battery is measured by reference to the electromotive force of one single element, or by the *Constant n.* This is determined by bringing the Condenser instead of the Cable (see Fig. 5) into the current by removing the plug p to p'.

The Condenser is first charged during 1 minute by aid of 1 element through s and u in the Discharge-key by depressing q. The Condenser is thereon, by releasing q and depressing r, discharged to Earth through b, the Galvanometer and c to Earth; the deflection u is then read. The Condenser is again charged, but with the whole Battery, in removing the wire v and binding the wire x to the screw s, and for the discharge is now used a Shunt, which varies until the deflection is as before $= u$. If the Shunt has a resistance $= s$, and the Galvanometer a resistance $= g$, the multiplying power of the Shunt will be $= \frac{s+g}{s}$, which may be put $= n$, and the Battery will thus work with a strength of n elements.

Instead of the variable Shunt is generally used a constant Shunt, and the two discharges then give two different deflections: u and u'. The Constant n is then $= \frac{u'}{u}$. Should by u' a Shunt v_2 have been used, then n is $= \frac{v_2 u'}{u}$.

23. CONSTANT ϕ OF THE GALVANOMETER.

The sensibility of the Galvanometer, which is indicated by the *Constant* ϕ, is determined as follows: only 1 element is used as Battery (see Fig. 6); the one end of a Resistance-coil of 10000 S.E. is connected to the element; its other end is connected through the Key S.K and the Galvanometer to Earth; a Shunt with resistance s' and multiplying power v' is used. When a deflection ϕ has thus been obtained, there will be found according to Ohm's Law:

$$v' \phi = \frac{1 \text{ element}}{10000 \text{ S.E.}}, \text{ or:}$$

$$v' \phi = \frac{1}{10000 \times \cdot 935} \text{ Ohms.}$$

If a sufficiently great Resistance-coil, say of 2,000,000 Ohms, is attainable, then the constant ϕ of the Galvanometer may be determined by using the whole Battery of, say, 200 cells. This facilitates the test, as it is now not any longer necessary to determine the constant of the Battery, namely the strength of the Battery compared to the strength of the one cell, which was used before at this test.

24. CALCULATION OF THE INSULATION.

The current is first led only into the *Leading wires*, which are not yet connected to the Cable. After ½ minute the plug of the Galvanometer is removed, and after another ½ minute the deflection, say u', is read. If the deflection after 1 minute from Cable and *Leading wires* is U, then the deflection from the Cable only will be:

$$U - u' = U'.$$

If a Shunt s with a multiplying power v has been used, then the deflection U' has to be multiplied with v, and $v\,U'$ is then a measure for the Insulation. The greatness s of the Shunt is in inverse proportion to the length of the Cable.

The Shunt has, as the Galvanometer, always to be well isolated.

It has to be observed that the deflection ϕ is taken on the same side of the zero on the scale, and, if possible, at the same point of the scale as the deflection U' from the Cable.

When these two deflections are compared, we obtain:

$$v'\,\phi : v\,U' = \frac{1}{10000 \times \cdot 935} : \frac{n}{x},$$

or, the resistance x of the Insulation is

$$= \frac{n \times v' \times \phi \times 10000 \times \cdot 935}{v\,U'}.$$

If the Galvanometer has a *very slight sensibility*, the Constant ϕ can be determined by the whole Battery, that is to say, by n elements, and should a Shunt be used with the multiplying power v_2, there will be found:

$$v_2\,\phi = \frac{n}{10000 \times \cdot 935}, \text{ or } x = \frac{v_2 \times \phi \times 10000 \times \cdot 935}{v\,U'}.$$

As this equation is independent of n, it is in this case unnecessary to determine or, that is to say, unnecessary to know the strength of the Battery.

As the Insulation is in inverse proportion to the length of the Cable, which can be put $= l$ knots, the *Insulation per knot* will be

$$= \frac{n \times v' \times \phi \times 10000 \times \cdot 935 \times l}{v\,U'}.$$

The resistance of the Insulation diminishes as the *temperature* increases, and if the resistance $x\,l$ is measured at, for instance, t degrees under or over 75° F., the resistance calculated at 75° F. will, at Hooper's Core, be $\frac{x\,l}{1\cdot026^t}$, or $x\,l \times 1\cdot026^t$ (see Table II.). This number with which it has been necessary to divide or multiply the result, so as to transfer it from one temperature to another, is named the *Coefficient of the Temperature*. When therefore the Insulation has been measured at t degrees under 75°, the *Insulation per knot at* 75° will be

$$= \frac{n \times v' \times \phi \times 10000 \times \cdot 935 \times l}{v \times U' \times 1 \cdot 026^t}.$$

The resistance at 75° F. for Gutta-percha will be found by using in the formula, instead of $1 \cdot 026^t$ at Hooper's Core, about $1 \cdot 076^t$ at ordinary Gutta-percha (see Table III.), and $1 \cdot 080^t$ at Willoughby Smith's Gutta-percha (see Table IV.).

When the *temperature* cannot be correctly measured by a thermometer, as for instance when the Cable is in a tank, sometimes full of water, sometimes without, or when it is paid out into the sea, the temperature of the Cable may be calculated by its existent copper-resistance, when its copper-resistance at 75° F. is known.

Is the resistance of a Cable per knot at 75° F. known to be 4·25 Ohms, and the existent Resistance is 4·00, then the temperature of the Cable is found as follows:

$$4 \cdot 25 \, (1 - \cdot 0021 \, (75 - t^0)) = 4 \cdot 00,$$

or
$$\frac{4 \cdot 25 - 4 \cdot 00}{4 \cdot 25} = \cdot 0021 \, (75 - t^0),$$

which gives
$$t = 47^\circ.$$

Should it be required to determine the Insulation after 2 *minutes'* charge, the deflection is read after 2 minutes, and the calculation made just in the same way as above mentioned, where the deflection is determined after 1 minute.

Should the calculation be made by *logarithms*, the following formula is used:

$$\log. x = \log. n + \log. v' + \log. \phi + \log. 10000 + \log. \cdot 935 - t \log. 1 \cdot 026 - \log. v - \log. U' + \log l.$$

25. INSULATION FOUND BY LOSS OF CHARGE.

The light-beam on the scale of the Galvanometer is often found very unsteady during the Insulation-test. This may be occasioned by the Battery being strongly polarized, or by the connection to Earth being faulty, or by adjoining machines making the Test-table shake, or by Cables being coiled into tanks close to the Cable about to be tested, or in a laid Cable by earth-currents. This unsteady deflection is particularly found with an India-rubber Cable, and arises possibly in part from the India-rubber reacting so strongly against the electricity, that the charge which is sent into the Cable is quickly driven back again, and creates a deflection on the scale in a direction opposite the direction of the principal deflections, while the charge entering into Gutta-percha Cables is more easily imbibed by the Gutta-percha.

For Cables with India-rubber it may therefore be advisable to certify the Insulation by also determining the *loss of charge.* If a Cable, charged by a Battery of 10 to 20 elements for 1 minute, isolated for 1 minute $= t$ and discharged, gives the deflection u', and a Cable, charged for 1 minute and then instantly discharged, gives a deflection u, then the charge will fall down to *half charge* in a time of t' minutes, which can be found by:

$$t' = \frac{\log. \frac{1}{\cdot 5}}{\log. \frac{u}{u'}} t = \frac{0 \cdot 30103}{\log. \frac{u}{u'}} t.$$

The *Resistance of the Insulation per knot* in Megohms may then be expressed by $= \dfrac{1 \cdot 443 \times 60 \times t'}{C} = \dfrac{\cdot 4343 \times 60 \times t}{C \log. \frac{u}{u'}},$

where C is the Charge in Microfarads per knot, and t is expressed in minutes.

The Resistance found in this way will generally be higher than it really is after 1 minute's Insulation, and agrees better with the resistance of the 2^{d} minute, which depends on the absorption of electricity by the dielectric, or the electrification of the Cable, until it is fully charged.

EXAMPLE. If the deflection falls in 1 minute from 100 to 98·5, it will be found:

$$t' = \frac{0 \cdot 30103}{\log . \frac{100}{98 \cdot 5}} = \frac{0 \cdot 30103}{0 \cdot 00655} = 46^{m}.$$

The Resistance of the Insulation at the existing temperature is

$$= \frac{1 \cdot 443 \times 60 \times 46}{0 \cdot 46} = 8658 \text{ Megohms.}$$

26. INSULATION FOUND BY THE ELECTROMETER.

The Insulation of a Cable may also be found by the aid of an *Electrometer*. A very thin flat aluminium needle is suspended between two plates, charged with electricity. If the needle has a negative charge, it will be repelled from the one plate, which is negative relative to the other plate, and the motion of the needle will be indicated by the motion of the spot of light, reflected by a mirror, attached to the needle; the deflection will be sensibly proportional to the difference of charge in the two plates.

The one pole of the Battery is to Earth, its other pole is permanently connected with one plate of the Electrometer, and by a short contact of 15 seconds with the other plate, which is in connection with the Cable. The two plates are therefore, when the short contact is first broken, at the same potential or electromotive force; but the potential of the plate connected with the Cable will fall, in consequence of the leakage through the dielectric of the Cable, while the potential of the other will remain unchanged and the spot of light will move from its first undeflected position.

As the deflection ought only to increase in a certain proportion, the good condition of the Cable may be ascertained by observing the deflection every fifth or tenth minute.

The Insulation I of a Cable is calculated by the following formula:

$$I = \frac{\cdot 4343\, t}{C \log. \frac{u}{u_1}},$$

where C is the charge in Microfarads, u the first observed deflection on the Electrometer scale, and u_1 the deflection after any time t, expressed in seconds.

Example.—If the deflection after $1^m\ 45^s$ is 395, and after $2^m\ 15^s$ is 391·5, and the charge is = ·44, then:

$$I = \frac{\cdot 4343 \times 30}{\cdot 44 \times \log. \frac{395}{391 \cdot 5}} = 7660 \text{ Megohms.}$$

The Electrometer is supposed to have, compared with the Galvanometer, some advantages, when used by testing short coils of high resistance, or Cables in way of sheathing, while machinery is in motion, or by testing several Cables at the same time, specially when long tests of electrification are taken, or by testing a paid-out Cable affected by earth-currents. But if the Electrometer is damp, its indications are incorrect, and as, in spite of every precaution, it is still difficult to keep it from dampness, it is therefore not safe for the Insulation test of a Cable to depend only on an Electrometer.

27. STRONG BATTERIES WITH CHANGING CURRENTS.

It is desirable at the daily *testing of the Core* to have, for half an hour before the testing, a Battery of 500 elements with reversing current connected to the Core. The *Insulation* test is then to be taken by connecting the Core, first, for 5 minutes to the Zinc-pole of the Battery, reversing the current for 2 minutes, leaving the Core to Earth until it is quite discharged, and then connect it for 5 minutes to the Copper-pole, noting down the deflection at every minute; the deflections obtained by the two currents ought to fall just in the same proportion.

The same operation is performed at the *final test* of a Cable, only the deflections are in this case noted down for 15 minutes, instead of 5 minutes.

28. EXAMPLES.

EXAMPLE 1.

Length of India-rubber Core = 5 knots.
Temperature = 70° F.
Number of elements (generally 250) here = 100.
Resistance of Galvanometer = 5850.
Deflection from the Leading wires = 3.
Shunt at Core = o; $v = \infty$.
Shunt at Galvanometer =10 Ohms; $v' = 586$.
Shunt at Battery = 100 Ohms; $v_2 = 59 \cdot 5$.

The following eight columns are to be filled up in a *journal;* Nos. 1, 3, and 5 are given, Nos. 4 and 6 are read, and the others are calculated.

Shunt at Battery.	Constant n of Battery.	Shunt at Galvanometer.	Constant ϕ of Galvanometer.	Shunt at Core.	Deflection after 1^{m}.	Total Insulation at 75°.	Insulation per Knot at 75°.
1	2	3	4	5	6	7	8
100	93·40	10	260°	0	139°	900	4500

If the deflection is with 1 element = 280° and with 100 elements and a Shunt of 100 = 440°, then n is =

$$\frac{59{\cdot}5 \times 440}{280} = 93{\cdot}40.$$

The coefficient of the temperature, or $1{\cdot}026^5$, is found in the Table II. = 1·137.

Total Insulation at 75° =

$$\frac{n \times v' \times \phi \times 10000}{U'} = \frac{93{\cdot}40 \times 586 \times 260 \times 10000}{139 \times 1{\cdot}137} = 900 \text{ Megohms.}$$

Total Insulation per knot at 75° = 900 × 5 knots = 4500 Megohms.

If the calculation be made by *logarithms*, it will be found:

$$\log. x = \log. n + \log. v' + \log. \phi + \log. 10000 - \log. 1{\cdot}137 - \log. U' + \log. 5.$$

$$\begin{array}{lll}
\log. 93{\cdot}40 = 1{\cdot}9703469 & & \log. 1{\cdot}137 = 0{\cdot}0557605 \\
\log. 586{\cdot}0 = 2{\cdot}7678976 & & \log. 139 \quad = 2{\cdot}1430148 \\
\log. 260 \quad = 2{\cdot}4149733 & & \overline{\phantom{2{\cdot}1987753}} \\
\log. 10000 = 4{\cdot}0000000 & & \qquad\quad 2{\cdot}1987753 \\
\qquad \overline{\phantom{4{\cdot}0000000}} & 11{\cdot}1522178 & \\
 & 2{\cdot}1987753 & \\
 & \overline{\phantom{11{\cdot}1522178}} & \\
\log. 900 \quad = & 8{\cdot}9544425 & \\
\log. 5 \quad\;\; = & 0{\cdot}6989700 & \\
 & \overline{\phantom{11{\cdot}1522178}} & \\
\log. 4500 & 9{\cdot}6534125 &
\end{array}$$

EXAMPLE 2.

Length of India-rubber Cable = 100 knots.
Temperature .. .. .. = 70° F.
Number of Elements .. .. = 100.
Resistance of Galvanometer = 5955 Ohms.
Shunt at Cable .. .. .. = 3000; $v = 2{\cdot}985$.
Shunt at Galvanometer .. = 50; $v' = 120{\cdot}1$.
Shunt at Battery .. .. .. = 80; $v_2 = 75{\cdot}44$.

Shunt at Battery.	Constant n of Battery.	Shunt at Galvanometer.	Constant ϕ of Galvanometer.	Shunt at Cable.	Deflection after 1^m.	Total Insulation at 75°.	Insulation per Knot at 75°.
1	2	3	4	5	6	7	8
80	97	50	540°	3000	412°	45·00	4500

$$x = \frac{97 \times 120{\cdot}1 \times 540 \times 10000 \times 100}{2{\cdot}985 \times 412 \times 1{\cdot}137} = 4500 \text{ Megohms.}$$

EXAMPLE 3.

Length of Gutta-percha Cable = 75 knots.
Temperature .. .. .. = 60° F.
Number of Elements .. .. = 200.
Resistance of Galvanometer = 10560.
Shunt at Cable .. .. .. = 1500; $v = 8{\cdot}04$.
Shunt at Galvanometer .. = 70; $v' = 151{\cdot}86$.
Shunt at Battery .. .. = 42; $v_2 = 25{\cdot}24$.

Shunt at Battery.	Constant n of Battery.	Shunt at Galvanometer.	Constant ϕ of Galvanometer.	Shunt at Cable.	Deflection after 1^m.	Total Insulation at 75° F.	Insulation per Knot at 75°.
1	2	3	4	5	6	7	8
42	252·42	70	148°	1500	390°	6	450

$$x = \frac{252{\cdot}42 \times 151{\cdot}86 \times 148 \times 10000 \times 75}{8{\cdot}04 \times 390 \times 3{\cdot}013} = 450 \text{ Megohms.}$$

EXAMPLE 4.

Length of Gutta-percha Core = 2 knots.
Temperature .. .. .. = 75° F.
Number of Elements .. = 200.
Resistance of Galvanometer = 5620.
Shunt at Core .. .. .. = 3000; $v = 2{\cdot}8733$.
Shunt at Galvanometer .. = 20; $v' = 282$.
Shunt at Battery .. .. = 33; $v_2 = 171{\cdot}30$.

Shunt at Battery.	Constant n of Battery.	Shunt at Galvanometer.	Constant ϕ of Galvanometer.	Shunt at Core.	Deflection after 1^m.	Total Insulation at 75°.	Insulation per Knot at 75°.
1	2	3	4	5	6	7	8
33	171·30	20	188°	3000	252°	125	250

$$x = \frac{171{\cdot}30 \,.\, 282 \,.\, 188 \,.\, 10000 \,.\, 2}{252 \,.\, 2{\cdot}8733} = 250 \text{ Megohms.}$$

D.—THE INSULATION OF A JOINT.

29. PRACTICAL EXECUTION.

For this test, in addition to the before-named apparatuses, is used a well-insulated trough, 3 feet long, and full of water (see Fig. 7). The Joint, when it has become quite cool, and has been soaking in water for 3 hours, as well as a copper-plate P connected to an isolated copper-wire, is lowered into the trough.

The Battery is given the same strength as at the Insulation test, or 500 elements.

It is necessary first to try the *insulation of the trough* and Leading wires by loss in charge. By connecting P to *u*, and depressing *q* for 15 seconds, the plate P is charged from Z through the Key B. K and the wire *x*. The plate is instantaneously discharged by releasing *q* and depressing *r*, the discharge passing through *b*, the Galvanometer, and *c* to Earth. The trough is again charged, kept isolated for 1 minute and discharged. If the loss of charge, when the Leading wires are short, is more than 2—3 per cent., the trough is not well insulated, and its insulation must be improved.

A test should be taken to prove that all *connections are in order*. The Joint J is connected to *k*, and when *f* is depressed, the current from Z passes through B. K to the Joint, which is then charged; an induced current in the water of the trough is hereby produced, which current is taken up by the Plate P. After ½ minute *r* is depressed, whereby the Plate P is discharged through the Galvanometer to Earth.

The Plate P is connected to *s*, the Condenser to *u* and *q* is depressed; the Joint is connected to *k*, and *f* is depressed during 1 *minute*, in which time the Condenser becomes charged with that quantity of electricity, which passes the insulation. At the end of the 1 minute, *q* is released and *r* depressed. The charge of the Condenser passes then through *b*, the Galvanometer and *c* to Earth, and the greatness of the charge is determined by the deflection on the scale of the Galvanometer.

If the Joint is thereupon instantly *discharged* to Earth by releasing *f*, an induced current in the opposite direction of the first induced will be produced in the trough, and will, when P is connected to *b*, give the same deflection on the scale of the Galvanometer as the first current, if all is in order.

30. STANDARD FOR JOINTS.

No more electricity is allowed to pass in a certain time through a Joint to the Plate P, than would pass in the same time through a faultless core twice as long as the Joint, or 6 feet long. The test ought therefore first to be made with 6 feet of faultless core and then with the Joint. To simplify the test it may however be agreed, that the charge received through the Joint, which has been connected to the Battery during 1 minute, must not be larger than say ·0005 Microfarad or $\frac{1}{1000}$ part of the Charge of a Condenser, the charge of which is ·5 Microfarad. If the full charge of a Condenser through a Shunt, with a multiplying power of 2000 gives a deflection *u*, the charge, which the Condenser has received in 1 minute through the Joint, ought only to be so great, that when charged, it gives through a Shunt with a multiplying power of 2 a deflection not greater than *u*.

The condenser must be entirely discharged when used for testing Joints, and a special condenser ought therefore to be reserved for this use.

E.—THE SITUATION AND GREATNESS OF A FAULT.

31. SIGNS OF FAULTS.

Larger faults, as a break in the Conductor, or a hole in the India-rubber, are easily discovered, as there will be obtained a smaller charge or a smaller insulation than in the faultless Cable; small faults are more difficult to ascertain, but it is to be presumed that they exist:

When the *Copper-resistance* at 75° F. is found to be lower in the Cable than it was before in the Core;

When the *Charge* diminishes;

When the *Loss of Charge* of the Cable after 1 minute's charge and 1 minute's insulation increases, and is, for instance, at 60° F. with India-rubber more than 3 per cent., and with Gutta-percha more than 15 per cent.* of the original charge;

When at the *Insulation* test the fall of the deflection from the 1st to the 2nd minute is too small, and is, for instance, at 60° F. with India-rubber less than 20 per cent., and with Gutta-percha less than 4 per cent.

If a *fault* is small, the best plan is to enlarge it by increasing the number of elements in the Battery as much as possible, say until 100 elements in a paid-out Cable, and until 1000 elements in a Cable in course of manufacture, changing the current, for instance, every 5th minute, until the fault is perfectly broken down.

When the Zinc-pole is connected with the Cable, the Conductor will be coated with hydrogen and the iron wires with oxygen, and this polarization will create a current in the Cable, so that the Cable disconnected from the Battery will give a deflection on the Galvanometer-scale, say to the right. If the Copper-pole is connected with the Cable, the hydrogen on the Conductor will be reduced and replaced by oxygen, while the iron wires will be coated with hydrogen, and the Cable current will give a deflection in the opposite direction or to the left. There is a moment when these opposite actions of the hydrogen and the oxygen are apparently balanced, where the end of the wire is unpolarized and probably uncoated, and then only can its correct resistance be determined. The test is then quickly made, alternately with negative and positive currents, the mean of which is taken.

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* See L. Clark and R. Sabine: 'Electrical Tables and Formulæ,' 1871, p. 121.

When the Zinc-pole is connected with a broken Cable, its copper-resistance ought to diminish as the Conductor gets de-oxydized; but if it do not diminish in the first moment it may arise from the formation of hydrogen air-bubbles on the Conductor, increasing its resistance, and the current must then be kept on until the resistance is lowering and finally rests almost unchanged. It is well in a broken Cable to connect the Zinc-pole to the Conductor for a certain time, say 12 hours, and then change the current every 5th minute.

As the strength of the Cable-current may be equal to that of about one Daniell's cell, the larger the number of cells used in testing the more accurate will be the result.

The proper resistance of the fault will often be equal to the resistance of two or three miles of Core, so that the real distance to the fault is two or three miles less than that shown by the test.

32. TEST FROM BOTH ENDS OF THE CABLE.

The test can be taken from both ends of the Cable, when the Cable is in course of fabrication, or when the fault is so small, that it is possible to work through the Cable, or when there are two telegraph lines between two stations. This test, or the *loop test*, is independent of the resistance in the fault, and has always to be used where possible.

The *Cable*, in which it is presumed a fault at p (Fig. 8) is developed during the fabrication, is connected with its ends to m and n in such a way, that the fault is nearest to m, and thus nearest to the resistance-coil R.

The wire to *Earth*, which is generally connected to the point m of the Wheatstone Bridge, is removed, as the current to Earth is here supposed to pass through the fault.

The *Battery* is given as many elements as possible.

Ratio of balance is to be varied until the proportion is found, by which the situation of the fault is determined with the greatest accuracy.

The copper-resistance R in the faultless Cable is supposed to be known from earlier tests; the length of the Cable is l. When the fault has shown itself, the resistance of the greater length np is put $= y$, the resistance of the smaller length $mp = z$, and the resistance in the fault $= q$. The resistance R has now to be decreased to R′ to make the needle of the Galvanometer stand on zero.

Then there is given:

$$y + z = R$$

and $$y + q = R' + z + q, \text{ or } y = R' + z.$$

Thus will be found:

$$z = \frac{R - R'}{2}.$$

The distance x of the fault from m is then found from the equation:

$$\frac{R}{z} = \frac{l}{x}, \text{ or } x = \frac{z\,l}{R}.$$

Example.

Length of the Cable = 120 knots.
$R = 500$ Ohms.
$R' = 160$ Ohms.

Then there is given:

$$y + z = 500, \text{ and } y = 160 + z.$$

Thus will be found:

$$z = 170, \text{ and } x = \frac{170 \times 120}{500} = 40{\cdot}8 \text{ knots.}$$

38. TEST FROM ONE END OF THE CABLE.

a. Test by Copper-resistance.

Where there is at the fault *full connection* to Earth, the copper-resistance in the length $n\,p$ is measured. Should this resistance be $= r$, whilst the resistance in the whole Cable, which has a length l, is before found $= R$, then the length $n\,p$ is $= \frac{r \times l}{R}$.

b. Test by Blavier's Method.

This method is used when, as generally happens, there is *not* at the fault *full* connection to Earth. To determine this fault with as much accuracy as possible, it is well to enlarge the fault by charging the Cable for some time with a changing current from a strong Battery.

The Copper-resistance in the faultless Cable is $= R$; the resistance in the Cable with fault and isolated at the end m is $= R_1$; and the resistance of the Cable with fault and with the end m connected to Earth is $= R_2$.

The resistances in the lengths $n\,p$ and $m\,p$ and in the fault are as before $= y$, z and q.

Then there is given:

$$R = y + z$$

$$R_1 = y + q$$

$R_2 = y + \frac{z\,q}{z + q}$, where $\frac{z\,q}{z + q}$ is the total resistance in z and q.

There now is found:

$$R - z = R_1 - q, \text{ or } q = R_1 - R + z$$

$$R - z = y = R_2 - \frac{z\,q}{z + q}, \text{ or } R - z = R_2 - \frac{z\,(R_1 - R + z)}{R_1 - R + 2z}.$$

Both sides of the equation multiplied with $R_1 - R + 2z$ gives:

$$z^2 + 2\,(R_2 - R)\,z = -R^2 - R_1R_2 + R\,R_1 + R\,R_2$$

$$z = R - R_2 + \sqrt{R_2^2 - R_1R_2 + R\,R_1 - R\,R_2}$$

$$y = R - z = R_2 - \sqrt{R_2^2 - R_1R_2 + R\,R_1 - R\,R_2}$$

The resistance in $n\,p$ being thus determined, the situation of the fault is found as before.

EXAMPLE.

Length of the Cable = 120 knots.
$R = 500$ Ohms.
$R_1 = 400$ Ohms.
$R_2 = 379$ Ohms.

Then there is found:

$$z = 160, \text{ and } y = 340.$$

Thus the length np is $= \frac{340 \times 120}{500} = 81 \cdot 6$ knots.

c. Test by Charge.

If the fault is occasioned by a break in the copper-wire, whilst the India-rubber is quite sound, the situation of the fault is found by charging the Cable from one end, determining the greatness of the charge, and dividing this number with the known charge per knot of the Cable.

TESTING AT LAYING OF A CABLE.

34. *Electrical Arrangement on Ship and on Shore.*

1. When *on Ship* (Fig. 9) f is depressed, the current goes from h through k, b and the testing screw T of the Commutator into the Cable connected to the screw C, and isolated in a Commutator at its other end on Shore. By opening the Short-current Key S.K, the current goes through the Galvanometer with Shunt, and a deflection is obtained.

The regular fall of the deflection indicates the good condition of the Cable; by a lowering of Insulation the deflection will increase.

By disconnecting T from, and connecting S to, the Cable, the ship is put in circuit for speaking.

2. *On Shore* (Fig. 10) the Cable end is connected to a Commutator, and a clock causes the arm $p\,q$ to touch for some few seconds every tenth minute the button r, thereby charging the Condenser and at the same time giving a throw on the Ship Galvanometer; when the arm $p\,q$ again touches

the button *t*, the Condenser is discharged through the Shore Galvanometer giving a deflection on the scale. Instead of a Commutator, an ordinary Charge and Discharge Key may be used worked by hand.

If the Insulation is lowering the discharge will get smaller, and in the event of a loss of Continuity, or a total loss of Insulation, no charge of the Condenser and no discharge at all will be obtained.

The ends of the Cable must always be kept dry and parafined.

If the Cable is permanently connected through a very *high Resistance* R_2 and a Galvanometer G_2 to Earth, Ship is able to signal at any time to Shore by either reversal or reduced tension, and Shore gets by this arrangement a permanent insulation and continuity test. For this resistance may be used a bar of selenium, or a plumbago line on glass, and a suitable Shunt is used to make the deflection on the Galvanometer scale of about 200 divisions.

3. Both Ship and Shore have to be provided with a complete set of testing apparatuses, always kept ready for testing at any moment.

35. *Instructions for Testing on Ship and on Shore.*

1. On *Ship*, the Cable being connected to Galvanometer for Insulation-test, the deflection is read every minute and noted down.

The Resistance of the Battery and the Constant of the Galvanometer being determined, the Insulation readings for every 10 minutes are reduced in the ordinary way in Megohms per knot.

2. *Ship* must note the time when the continuity-throws from Shore occur, which will be about every tenth minute.

3. *Ship* will reverse the Current every hour, whereby the discharge-throws on shore will also be reversed.

4. *Ship* will reverse the Current 10 minutes before noon, and Shore will acknowledge this by pressing in the stud *s* three times and bringing the arm *p q* in contact with *r*, thereby giving three kicks on the Ship Galvanometer. Ship then releases T and depresses S, and Shore having on its Commutator released T′ and depressed S′, all will be in readiness for speaking. Ship then gives Shore the time by sending a lot of dots, stopping at exactly twelve o'clock Greenwich time. Ship sends any necessary information, as distance run and miles paid out, as quickly as possible, always finishing by "insulate," which Shore station will immediately obey, both stations releasing S and S′ and depressing T and T′, and being again ready for the Insulation-test.

5. *Ship* not to send any communications except those ordered by the chief Electricians and Engineers.

6. On *Shore* the Condenser is every tenth minute, commencing at the full hour, connected through the arm *p q* and the button *r* of the Commutator for 10 seconds to the Cable, the charge abstracted from the Cable producing a throw on the deflection-scale on board; the Condenser is instantly afterwards discharged through the shunted Galvanometer G′ by the falling back of the arm *p q* to the button *t*. To make this reading very accurate, it is important to make it as high as possible. Shore must multiply these readings with the value of the Shunt, and enter the true value of each reading.

7. At reversals at the full hour except at noon *Shore* will not alter any connections, but simply note time and amount of throw on the Galvanometer G′; but at reversals not being at the hour, Shore will depress the stud *s* three times and join up for speaking, ready to receive messages from Ship.

8. *Shore* to make no communications whatever, or ask any questions, except in reply to demands from Ship. All information demanded to be given with as few words as possible.

9. *Shore* to keep a diary, in which the names of the electrician in charge and the clerk on duty are entered, so that the responsible party for any time can be found. In the diary all observations must be recorded in full and timed.

10. The testing room on *Shore* must be kept strictly private, and no one admitted except on business.

11. Should any loss of Insulation or any *Fault* occur, and Ship, having carefully examined all connections, has found that the extra loss of current is due to the Cable, the current is reversed, as a signal to Shore to join up for receiving messages, and if *speaking is possible* Ship may, for instance, direct Shore to remove end of Cable from the Commutator, carefully retrim it and isolate it, that Ship may take another Insulation-test.

Should the *Fault* make *speaking impossible*, Ship and Shore will proceed as follows:—

Shore having joined up for speaking until the next full 10 minutes, insulates for 10 minutes, puts to Earth for 10 minutes, and continues to insulate and put to Earth alternately every 10 minutes until the next full hour. Shore then again joins up 10 minutes for speaking, and commences again to insulate and put to Earth alternately every 10 minutes until the next full hour, and so on until signal is received from Ship.

12. From the day the *communication* with the Ship *ceases*, Shore will have daily to take two series of tests, each of twelve readings for Copper-resistance, six with Zinc to Cable, and six with Copper to Cable, alternately. One series of these tests to be taken at 9 A.M., and the other at 6 P.M.

13. *Records* of the tests made and results obtained are to be carefully kept both on Ship and Shore.

14. The above *regulations* can *only* be *modified* by order from the Ship. The strictest fulfilment is of the utmost urgency, and no excuse whatever for any neglect will be accepted.

FORMULÆ.

36. FORMULÆ FOR THE CHARGE OF CORES.

The *Charge* C *per knot* of a Core is determined by the following equation:

$$C = c \frac{E \,.\, l}{R \log. \frac{D}{d}},$$

where c is a constant, E is the electromotive force of the Battery, l the length in knots of the Core, R the resistance per knot of the Insulator, D the diameter of the Core, and d the diameter of the Conductor.

If for *Hooper's Core*, the following numbers are given:

$C = \cdot 45$, $R = 4000$, $D = \cdot 318''$, $d = \cdot 145''$, and if E is $= 1$ and $l = 1$, then c is $= 614$.

The *Charge* C *per knot* is then

$$= \frac{614}{4000 \log. \frac{D}{d}} = \frac{\cdot 1535}{\log. \frac{D}{d}} \text{ Microfarads.}$$

The *Charge* C *per knot* by *ordinary Gutta-percha Core* is found

$$= \frac{\cdot 1877}{\log. \frac{D}{d}} \text{ Microfarads.}$$

The *Charge* C *per knot* at *Willoughby Smith's Gutta-percha Core* is found to be

$$= \frac{15163}{\log. \frac{D}{d}} \text{ Microfarads.}$$

37. FORMULÆ FOR THE INSULATION OF CORES.

The *Insulation* per knot at 75° F. is:

At Hooper's Core .. .. $= 1\cdot 3 \times \log. \frac{D}{d}$ Megohms.

At ordinary Gutta-percha Core $= \cdot 077 \times \log. \frac{D}{d}$ „

At Willoughby Smith's Core $= \cdot 035 \times \log. \frac{D}{d}$ „

where D is the diameter of the Core, and *d* the diameter of the Conductor, and where the first four figures of the logarithm is regarded as a whole number.

The *Insulation* per knot at 75° F. of a Core with a Strand Conductor, calculated *by weights*, and not by diameters, is:

At Hooper's Core .. .. $= 1\cdot 3 \times \log. \sqrt{1 + 5\cdot 7 \frac{W}{w}}$

$$\left.\begin{array}{l}\text{At ordinary Gutta-percha}\\ \quad\text{Core .. ..}\end{array}\right\} = \cdot 077 \times \log.\sqrt{1 + 6\cdot 9\frac{W}{w}}$$

$$\left.\begin{array}{l}\text{At Willoughby Smith's}\\ \quad\text{Gutta-percha Core ..}\end{array}\right\} = \cdot 035 \times \log.\sqrt{1 + 6\cdot 9\frac{W}{w}}$$

where W is the weight of the Dielectric and w the weight of the Conductor, and where the first four figures of the logarithm is regarded as a whole number.

38. FORMULÆ FOR THE SPEED IN CABLES.

The *Speed* of working a Cable is proportionate to:

$$\frac{S}{l^2 \times C}, \text{ or } \frac{1}{l^2 \times C \times r},$$

where S is the specific conductivity of the copper, l the length of the Cable, C the Charge of the Cable per knot, and r the resistance of the copper per knot.

When the holes in the machine, in which the copper-wires are drawn out, are worn out, the diameter of the copper-wires, and consequently their conductivity will increase, and the speed of the Cable would also increase, if the charge did not generally increase at the same time, whereby the speed will be again diminished.

When it is fixed, that the specific conductivity S shall be not less than 90 per cent., and the charge C not more than ·44 Microfarad, then the speed through 1 knot of Cable will be proportionate to $\frac{90}{\cdot 44} = 205$; and the charge may increase to ·45 and ·46 Microfarad, without the speed being altered, if the conductivity of the copper at the same time increases to 93·25 and 94·30, because $\frac{93\cdot 25}{\cdot 45} = 205 = \frac{94\cdot 30}{\cdot 46}$.

As the Charge of the Core is inversely proportionate to log. $\frac{D}{d}$, and the resistance of the Copper is inversely proportionate to d^2, where D is the diameter of the Core in mils. (or thousandths of an inch), and d the diameter of the Conductor in mils., the working *Speed* can be expressed by:

$$\text{constant} \times \frac{d^2 (\log. D - \log. d)}{l^2}.$$

The *Speed* or number of words per minute is:—
At Hooper's Core, with Morse's Apparatus:

$$700 \frac{d^2 (\log. D - \log. d)}{l^2};$$

at Hooper's Core, with Reflecting Galvanometer:

$$7700 \frac{d^2 (\log. D - \log. d)}{l^2};$$

by Gutta-percha Core, with Morse's Apparatus:

$$530 \frac{d^2 (\log. D - \log. d)}{l^2};$$

by Gutta-percha Core, with Reflecting Galvanometer:

$$5830 \frac{d^2 (\log. D - \log. d)}{l^2}.$$

The obtained maximum speed is 50 per cent. higher than the above-named working speed.

Example 1.—A Hooper's Core, with 300 lbs. Copper and 200 lbs. India-rubber, or with $d = \cdot 145''$ and $D = \cdot 318''$, will, by a distance of 900 nautical miles, give a speed with Morse's Apparatus of

$$700 \frac{145^2 (\log. 318 - \log. 145)}{900^2} = 6 \cdot 2 \text{ words per minute.}$$

The maximum speed will be about 9 words per minute.

With a reflecting or mirror Galvanometer, the speed will be $11 \times 6 \cdot 2 = 68$ words per minute.

Example 2.—A Hooper's Core, with 180 lbs. Copper and 180 lbs. India-rubber, or with $d = \cdot 110''$ and $D = \cdot 290''$, will, by a distance of 350 nautical miles, give a speed with Morse's Apparatus of

$$700 \frac{110^2 (\log. 290 - \log. 110)}{350^2} = 29 \text{ words per minute.}$$

Example 3.—A Core with 200 lbs. Copper and 200 lbs. Gutta-percha, or with $d = \cdot 119''$ and $D = \cdot 335''$, will, by a distance of 400 nautical miles, give a speed with Morse's Apparatus of

$$530 \frac{119^2 (\log. 335 - \log. 119)}{400^2} = 21 \text{ words per minute.}$$

Example 4.—A Core with 300 lbs. Copper and 400 lbs. Gutta-percha, or with $d = \cdot 147''$ and $D = \cdot 467''$, will, by a distance of 1857 nautical miles, as the Atlantic Cable of 1866, give a speed with a reflecting Galvanometer, or the mirror system, of

$$5830 \frac{147^2 (\log. 467 - \log. 147)}{1857^2} = 18 \cdot 3 \text{ words per minute.}$$

The maximum speed obtained with this Cable is 25 words per minute.

39. FORMULÆ FOR THE WEIGHTS OF CONDUCTOR AND INSULATOR.

The weight per knot of a copper-wire is $= \frac{d^2}{55}$ lbs., where d is the diameter of the wire in mils. (thousandth parts of an inch).

The weight per knot of a copper strand is $= \frac{d^2}{70 \cdot 4}$ lbs.

The weight per knot of India-rubber is $= \frac{D^2 - d^2}{401}$ lbs., where D is the diameter of the Core, and d the diameter of the Conductor in mils.

The weight per knot of Gutta-percha is $= \frac{D^2 - d^2}{491}$.

Example.—A Gutta-percha Core is required, which has the same charge and the same weight of copper as an India-rubber Core with the weight per knot of 300 lbs. copper and 200 lbs. India-rubber. What is the weight of Gutta-percha per knot?

The charge of the India-rubber Core is found before to be = ·45 Microfarad.

Then we have:

$$\cdot 45 = \frac{\cdot 18769}{\log. \frac{D}{\cdot 145}}; \quad \log. \frac{D}{\cdot 145} = \cdot 417; \quad D = \cdot 379'';$$

$$300 = \frac{d^2}{55}; \quad d = \cdot 145''.$$

The weight of Gutta-percha is:

$$\frac{D^2 - d^2}{491} = \frac{\cdot 379^2 - \cdot 145^2}{491} = 250 \text{ lbs.}$$

40. FORMULÆ FOR THE DIAMETERS OF CORES.

The outer diameter D in mils. of a Gutta-percha Core, of which the strand conductor weighs c lbs., and the Gutta-percha g lbs. per knot, is:

$$D = \sqrt{c \times 70{\cdot}4 + g \times 491}.$$

The outer diameter D in mils. of an India-rubber Core, of which the conductor weighs c lbs. and the India-rubber i lbs. per knot, is:

$$D = \sqrt{c \times 70{\cdot}4 + i \times 401}.$$

Example.—If at a Gutta-percha Core the copper strand weighs 200 lbs. and the Gutta-percha 200 lbs. per knot, then:

$$d = \sqrt{200 \times 70{\cdot}4} = 119, \text{ and}$$

$$D = \sqrt{200 \times 70{\cdot}4 + 200 \times 491} = 335.$$

When the Dielectric has the same weight as the Conductor, or when $w = W$, then:

$$\frac{D}{d} = \frac{\sqrt{w \times 70{\cdot}4 + W \times 491}}{\sqrt{w \times 70{\cdot}4}} = \sqrt{1 + 6{\cdot}9744 \frac{W}{w}} = 2{\cdot}82.$$

$$D = 2{\cdot}82 \times d = 2{\cdot}82 . 119 = 335.$$

41. FORMULÆ FOR THE DIAMETERS OF CABLES.

The outer diameter D of a bright iron Cable (a Cable without an outer covering) with n wires, each wire with a diameter d, is:

$$D = d . \frac{1 + \sin. \frac{180}{n}}{\sin. \frac{180}{n}}.$$

The inner diameter D′ of the iron covering at the Cable is:

$$D' = d \,.\, \frac{1 - \sin.\dfrac{180}{n}}{\sin.\dfrac{180}{n}}.$$

Example.—At a cable with 12 wires, No. 8, each with a diameter of ·165″:

$$D = \cdot165'' \times \frac{1 + \sin. 15^\circ}{\sin. 15^\circ} = \cdot165 \frac{1 + \cdot258819}{\cdot258819} = \cdot802''$$

$$D' = \cdot165'' \times \frac{1 - \cdot258819}{\cdot258819} = \cdot472''$$

TABLE I.

TEMPERATURE COEFFICIENT FOR CALCULATING THE RESISTANCE OF COPPER AT 75° F.

Temperature lower than 75°	Coefficient.	Logarithm of Coefficient.	Temperature higher than 75°	Coefficient.	Logarithm of Coefficient.
0	1·0000	·0000000	0	1·0000	·0000000
1	1·0021	·0009111	1	·9979	·9990870–1
2	1·0042	·0018202	2	·9958	·9981721–1
3	1·0063	·0027275	3	·9937	·9972553–1
4	1·0084	·0036328	4	·9916	·9963365–1
5	1·0105	·0045363	5	·9896	·9954597–1
6	1·0127	·0054808	6	·9875	·9945371–1
7	1·0148	·0063805	7	·9854	·9936126–1
8	1·0169	·0072782	8	·9834	·9927302–1
9	1·0191	·0082168	9	·9813	·9918018–1
10	1·0212	·0091108	10	·9792	·9908714–1
11	1·0233	·0100030	11	·9772	·9899835–1
12	1·0255	·0109357	12	·9751	·9890492–1
13	1·0276	·0118241	13	·9731	·9881575–1
14	1·0298	·0127529	14	·9711	·9872640–1
15	1·0320	·0136797	15	·9690	·9863238–1
16	1·0341	·0145625	16	·9670	·9854265–1
17	1·0363	·0154855	17	·9650	·9845273–1
18	1·0385	·0164065	18	·9629	·9835812–1
19	1·0407	·0173256	19	·9609	·9826782–1
20	1·0428	·0182010	20	·9589	·9817733–1
21	1·0450	·0191163	21	·9569	·9808666–1
22	1·0472	·0200296	22	·9549	·9799579–1
23	1·0494	·0209411	23	·9529	·9790473–1
24	1·0516	·0218506	24	·9509	·9781348–1
25	1·0538	·0227582	25	·9489	·9772204–1
26	1·0561	·0237050	26	·9469	·9763041–1
27	1·0583	·0246088	27	·9449	·9753858–1
28	1·0605	·0255107	28	·9429	·9744656–1
29	1·0627	·0264107	29	·9409	·9735435–1
30	1·0650	·0273496	30	·9390	·9726656–1
31	1·0671	·0282051	31	·9369	·9716932–1
32	1·0692	·0290590	32	·9348	·9707187–1
33	1·0713	·0299111	33	·9327	·9697420–1
34	1·0734	·0307616	34	·9306	·9687630–1
35	1·0755	·0316104	35	·9285	·9677819–1
36	1·0777	·0324979	36	·9264	·9667985–1
37	1·0798	·0333433	37	·9243	·9658130–1
38	1·0819	·0341871	38	·9222	·9648251–1
39	1·0841	·0350693	39	·9201	·9638350–1
40	1·0862	·0359098	40	·9180	·9628427–1

TABLE II.

TEMPERATURE COEFFICIENT FOR CALCULATING THE DIELECTRIC RESISTANCE OF HOOPER'S INDIA-RUBBER AT 75° F.

Difference in Temperature, t.	$1{\cdot}026\ t$.	t Log. 1·026.	Difference in Temperature, t.	$1{\cdot}026\ t$.	t Log. 1·026.
0	1·000	·00000	21	1·715	·23415
1	1·026	·01115	22	1·759	·24530
2	1·053	·02230	23	1·805	·25645
3	1·080	·03345	24	1·852	·26760
4	1·108	·04460	25	1·900	·27875
5	1·137	·05575	26	1·949	·28990
6	1·167	·06690	27	2·000	·30105
7	1·197	·07805	28	2·052	·31220
8	1·228	·08920	29	2·105	·32335
9	1·260	·10035	30	2·160	·33450
10	1·293	·11150	31	2·216	·34565
11	1·326	·12265	32	2·274	·35680
12	1·361	·13380	33	2·333	·36795
13	1·396	·14495	34	2·394	·37910
14	1·443	·15610	35	2·456	·39025
15	1·470	·16725	36	2·520	·40140
16	1·508	·17840	37	2·586	·41255
17	1·547	·18955	38	2·653	·42370
18	1·587	·20070	39	2·722	·43485
19	1·629	·21185	40	2·793	·44600
20	1·671	·22300			

TABLE III.

TEMPERATURE COEFFICIENT FOR CALCULATING THE DIELECTRIC RESISTANCE OF ORDINARY GUTTA-PERCHA AT 75° F.

Temperature Fahr.	Resistance.	Log. Resistance.	Temperature Fahr.	Resistance.	Log. Resistance.
32°	23·622	·373317	67°	1·801	·255514
33	21·947	·341375	68	1·673	·223496
34	20·391	·309439	69	1·555	·191730
35	18·945	·277495	70	1·444	·159567
36	17·602	·245562	71	1·342	·127753
37	16·354	·213624	72	1·247	·095867
38	15·195	·181701	73	1·158	·063709
39	14·117	·149742	74	1·076	·031812
40	13·116	·117801	75	1·000	·000000
41	12·186	·085861	76	·9418	·973959
42	11·322	·053923	77	·8870	·947924
43	10·520	·022016	78	·8354	·921895
44	9·774	·990072	79	·7867	·895809
45	9·081	·958134	80	·7410	·869818
46	8·437	·926188	81	·6978	·843731
47	7·839	·894261	82	·6572	·817698
48	7·283	·862310	83	·6190	·791691
49	6·767	·830396	84	·5829	·765594
50	6·287	·798444	85	·5490	·739572
51	5·841	·766487	86	·5171	·713575
52	5·427	·734560	87	·4870	·687529
53	5·042	·702603	88	·4586	·661434
54	4·685	·670710	89	·4319	·635383
55	4·353	·638789	90	·4068	·609381
56	4·044	·606811	91	·3831	·583312
57	3·757	·574841	92	·3608	·557267
58	3·491	·542950	93	·3398	·531223
59	3·244	·511081	94	·3200	·505150
60	3·013	·478999	95	·3014	·479143
61	2·800	·447158	96	·2839	·453165
62	2·601	·415140	97	·2674	·427161
63	2·417	·383277	98	·2518	·401056
64	2·245	·351216	99	·2371	·374932
65	2·086	·319314	100	·2233	·348889
66	1·938	·287354			

TABLE IV.

TEMPERATURE COEFFICIENT FOR CALCULATING THE DIELECTRIC RESISTANCE OF WILLOUGHBY SMITH'S GUTTA-PERCHA AT 75° F.

Temperature Fahr.	Resistance.	Log. Resistance.	Temperature Fahr.	Resistance.	Log. Resistance.
32°	27·913	·445807	67°	1·858	·269046
33	25·834	·412192	68	1·719	·235276
34	23·910	·378580	69	1·591	·201670
35	22·128	·344942	70	1·473	·168203
36	20·480	·311330	71	1·363	·134496
37	18·954	·277701	72	1·261	·100715
38	17·542	·244079	73	1·167	·067071
39	16·235	·210452	74	1·080	·033424
40	15·025	·176815	75	1·000	·000000
41	13·906	·143202	76	·9375	·971971
42	12·870	·109579	77	·8789	·943940
43	11·911	·075948	78	·8240	·915927
44	11·024	·042339	79	·7725	·887899
45	10·203	·008728	80	·7242	·859859
46	9·442	·975064	81	·6789	·831806
47	8·739	·941462	82	·6365	·803798
48	8·088	·907841	83	·5967	·775756
49	7·485	·874192	84	·5594	·747723
50	6·928	·840608	85	·5245	·719746
51	6·412	·806994	86	·4917	·691700
52	5·934	·773348	87	·4609	·663607
53	5·492	·739731	88	·4321	·635584
54	5·083	·706120	89	·4051	·607562
55	4·704	·672467	90	·3798	·579555
56	4·354	·638888	91	·3561	·551572
57	4·029	·605197	92	·3338	·523486
58	3·729	·571592	93	·3130	·495544
59	3·451	·537945	94	·2934	·467460
60	3·194	·504335	95	·2751	·439491
61	2·956	·470704	96	·2579	·411451
62	2·736	·437116	97	·2417	·383277
63	2·532	·403464	98	·2266	·355260
64	2·343	·369772	99	·2125	·327359
65	2·169	·336260	100	·1992	·299289
66	2·007	·302547			

TABLE V.

CONVERTING OF YARDS INTO KNOTS.

Yards.	Knots.	Yards.	Knots.	Yards.	Knots.	Yards.	Knots.
1	·000493	31	·015278	61	·030064	91	·044850
2	·000986	32	·015771	62	·030557	92	·045343
3	·001479	33	·016264	63	·031050	93	·045836
4	·001971	34	·016757	64	·031542	94	·046329
5	·002464	35	·017250	65	·032035	95	·046822
6	·002957	36	·017743	66	·032528	96	·047315
7	·003450	37	·018236	67	·033021	97	·047808
8	·003943	38	·018728	68	·033514	98	·048301
9	·004436	39	·019221	69	·034007	99	·048794
10	·004929	40	019714	70	·034500	100	·049287
11	·005421	41	·020207	71	·034993	200	·098571
12	·005914	42	·020700	72	·035485	300	·147856
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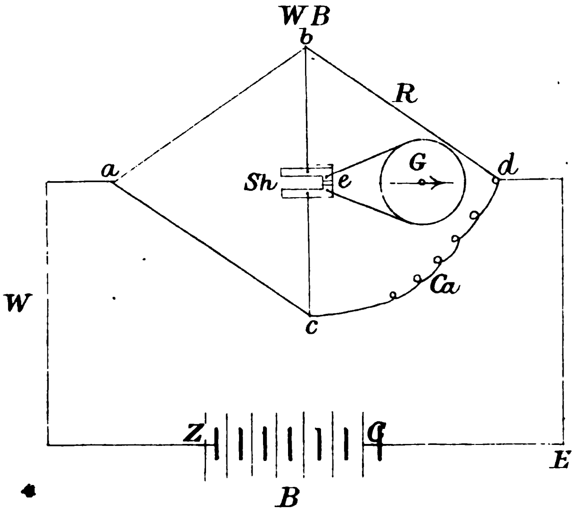

Fig. 2.

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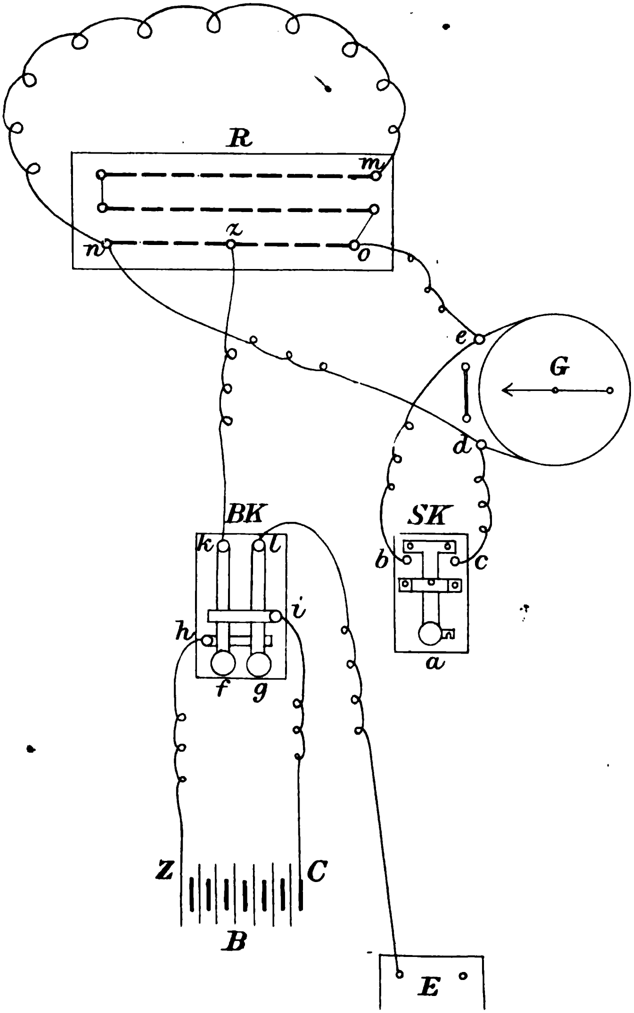

Fig. 3.

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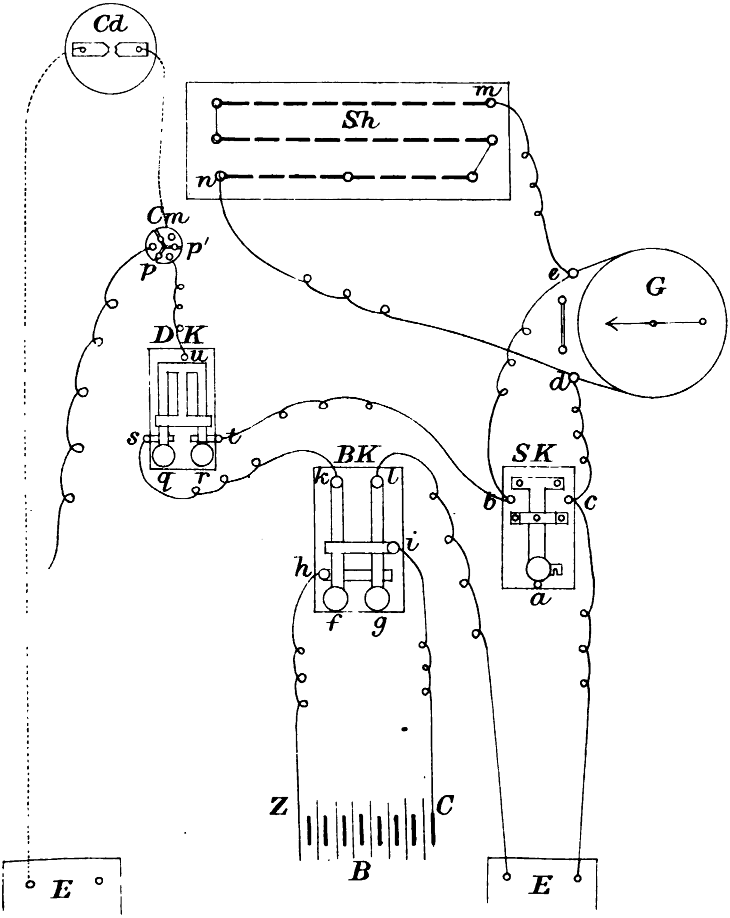

Fig. 4.

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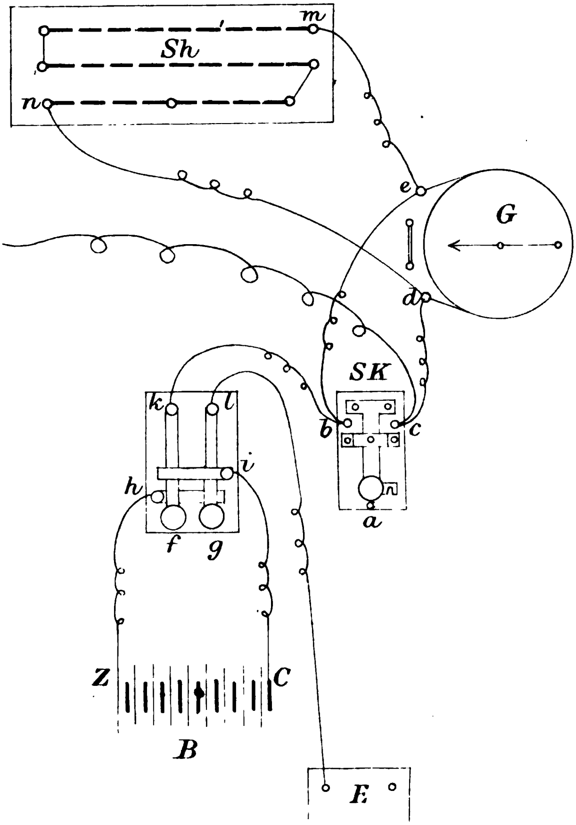

Fig. 5.

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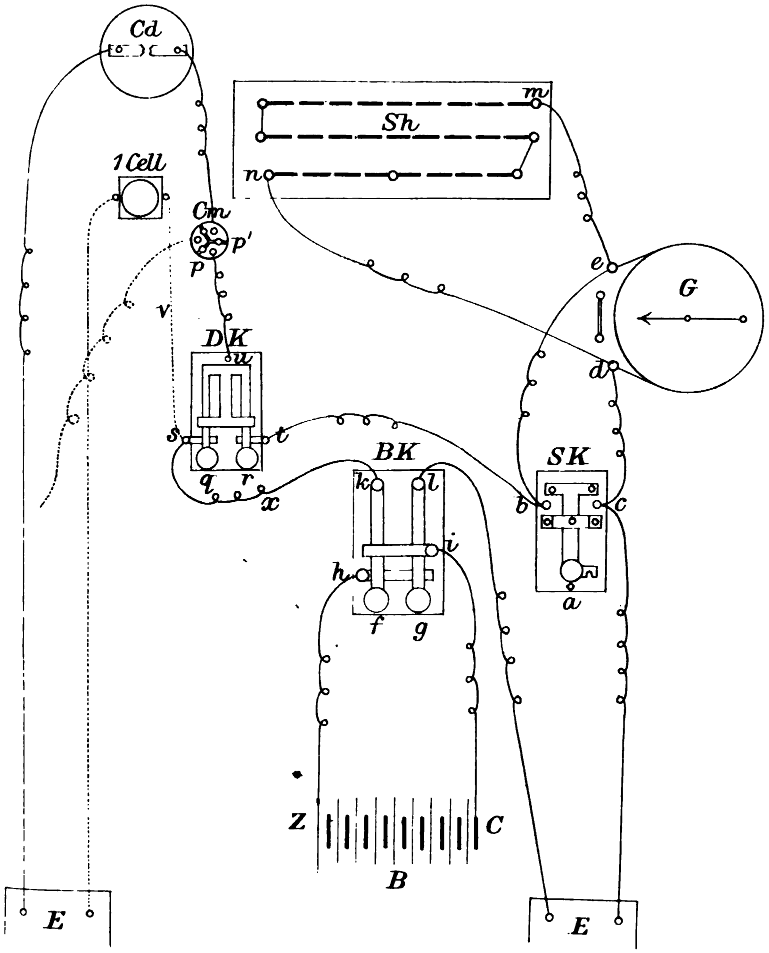

Fig. 6.

CONSTANT OF THE GALVANOMETER.

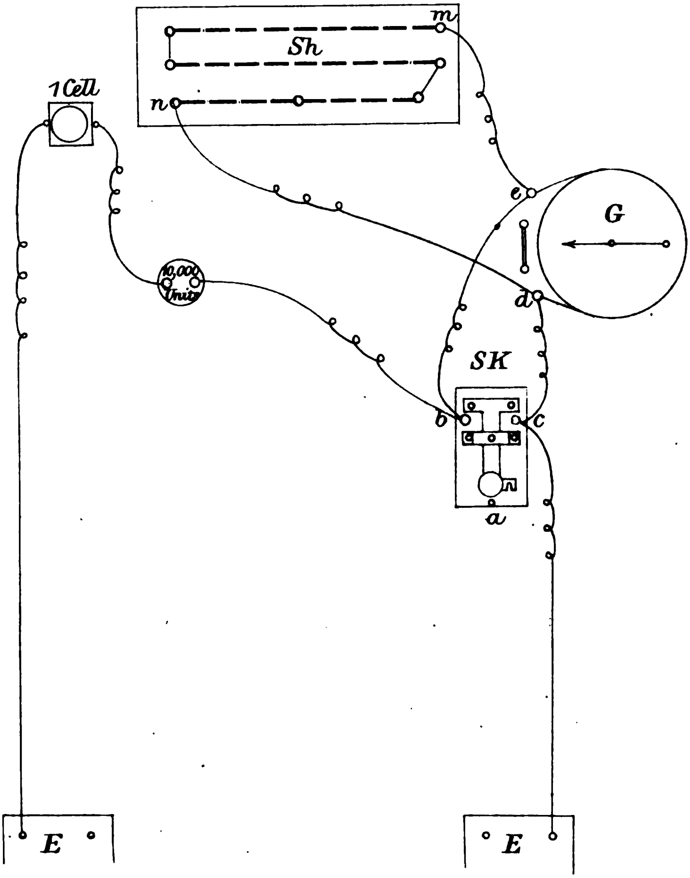

Fig. 7..

JOINT TEST.

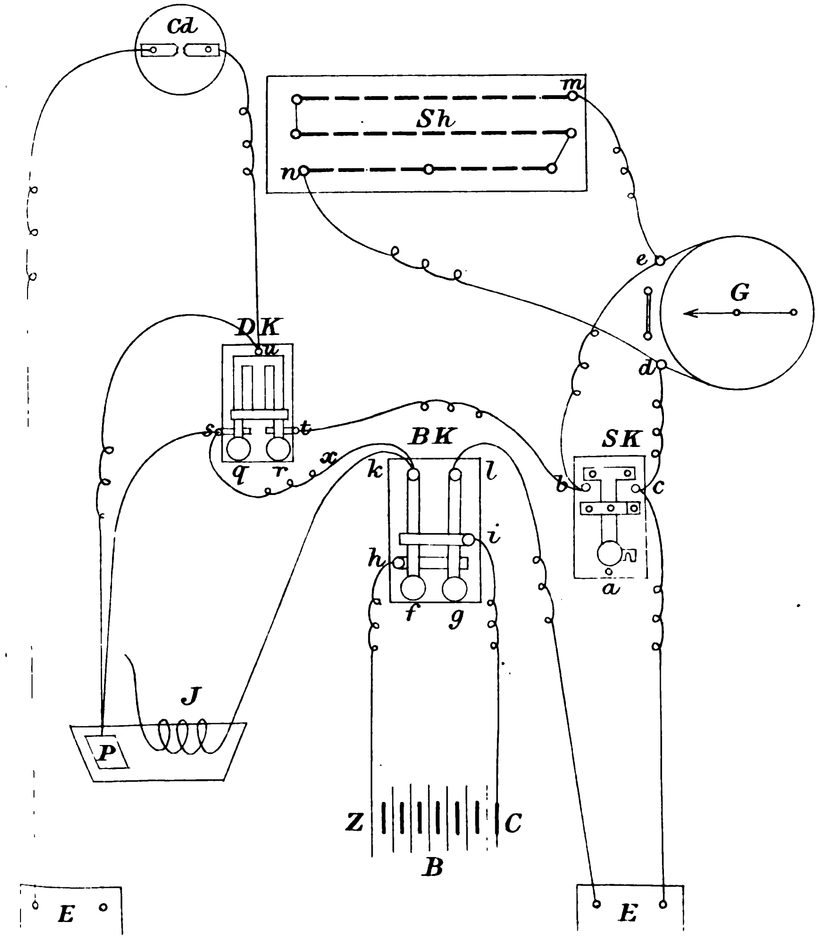

Fig. 8.

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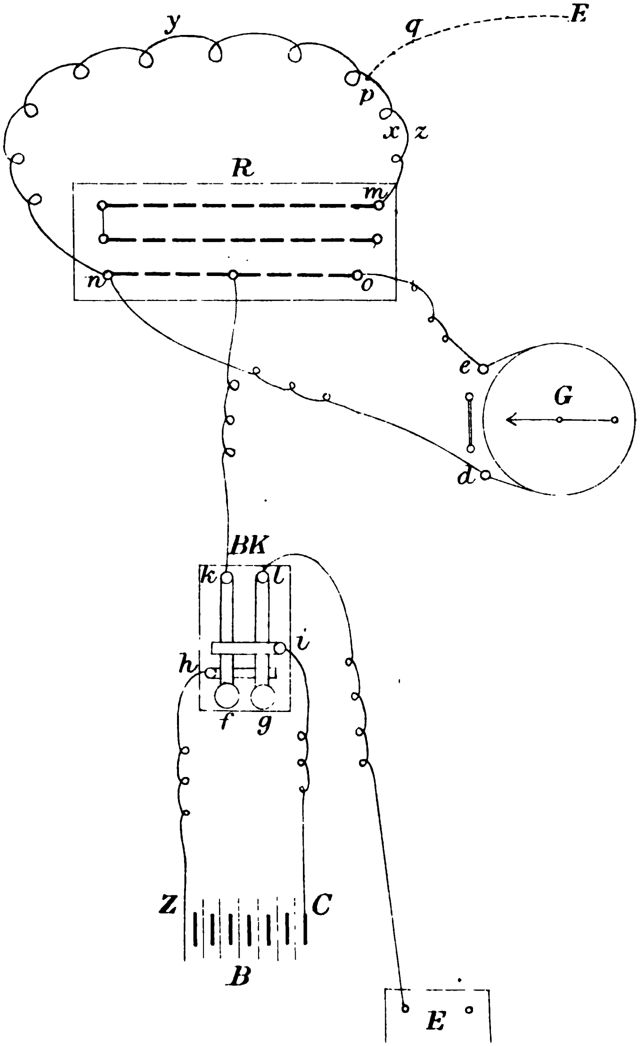


Fig. 9.

ON SHIP.

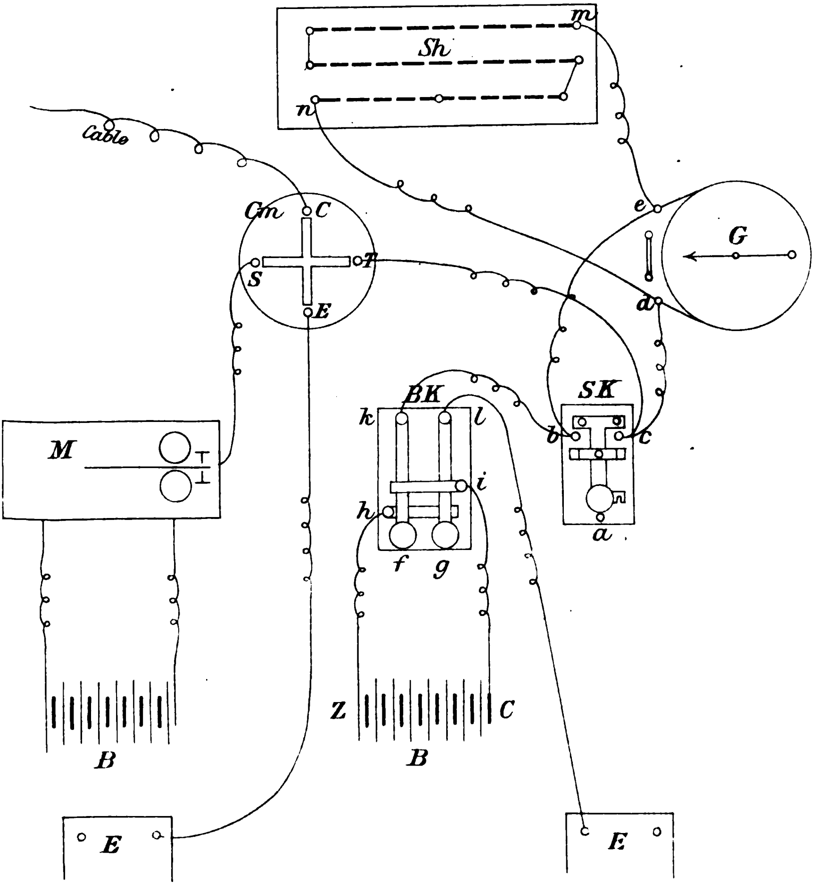
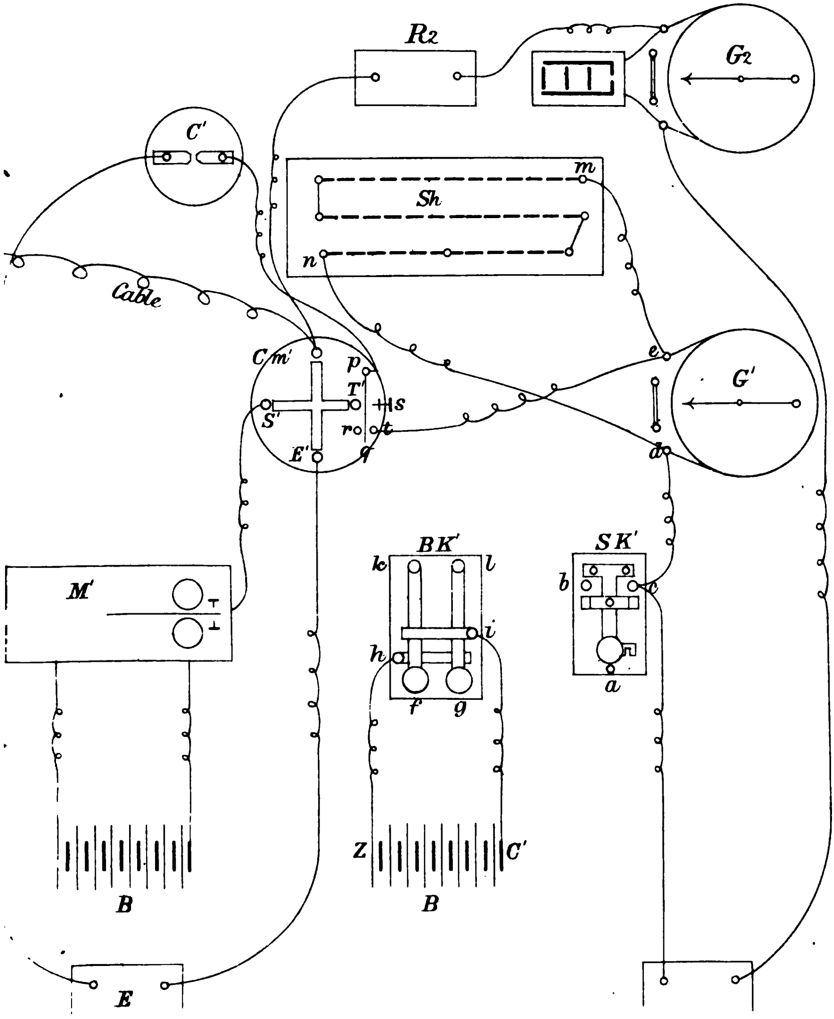


Fig. 10.

ON SHORE.



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